The Frontiers of Space

Technology and the Search for Life Elsewhere

by Dr. Edward C. Stone

The technology of the Space Age that began thirty-nine years ago with the launch of Sputnik has revealed the surprising diversity of the planets and moons in the solar system. Space technology can also provide a new perspective for understanding life on Earth through the search for life elsewhere. The first major step in this search was twenty years ago when the Viking mission landed on Mars.

The Viking Mission

The first of two Viking spacecraft landed on Mars on July 25, 1976 to search for evidence of life, past or present, and to return the first images from the surface of another planet. In many ways, Mars (Figure 1) is the planet most closely resembling Earth, and twenty years ago many attributes of Mars suggested the possibility of past or present life.

Figure 1

I can recall the excitement of seeing the first image from the surface of Mars as technology opened a new phase of in situ planetary exploration. The Viking landers scooped up samples of the Martian soil to analyze it for the presence of life or the residue of past life (the small trenches are visible in Figure 2). It was discovered that the reddish soil of Mars contains a highly oxidizing material and there is no atmospheric ozone layer to protect the surface from ultraviolet sunlight. As a result, organic materials on the surface are rapidly oxidized or destroyed by ultraviolet light, making the surface inhospitable to life today. This discovery led to a nearly 20- year hiatus in the search for life elsewhere in the solar system. The search has only recently been revived by discoveries about life on Earth.

Figure 2

Life in Extreme Environments

In 1977, just a year after the Viking landings, life was discovered proliferating in darkness around thermal vents on the Earth's ocean floor. Instead of needing sunlight, these ecosystems depend on chemical energy boiling up from the Earth's interior. Life has also been found at freezing temperatures underneath and within Antarctic sea ice and in rock from several miles below the surface in Washington state.

We now realize that life is more robust than imagined twenty years ago, thriving in extreme environments wherever there is liquid water and a source of energy. Many of these extremophiles were shown not to be bacteria, but a new form of life called *ArcAaea* independent of but sharing a common ancestor with the well known forms of life.

There is also evidence that life evolved more rapidly on Earth than previously thought. Ancient microfossils in Western Australian rocks that are about three-and-a-half billion years old indicate that life evolved very rapidly, likely appearing on Earth nearly four billion years ago.

Life on Mars?

Since life evolved very rapidly on Earth and is found in extreme environments, perhaps the pessimism from the Mars Viking landers was undeserved. Common to these observations of life is the presence of water and there was a lot of water on Mars at one time. Wide river channels (figure 3) that are much broader than any on Earth were carved by massive, episodic floods. Other areas (Figure 4) appear to be dry lake beds.

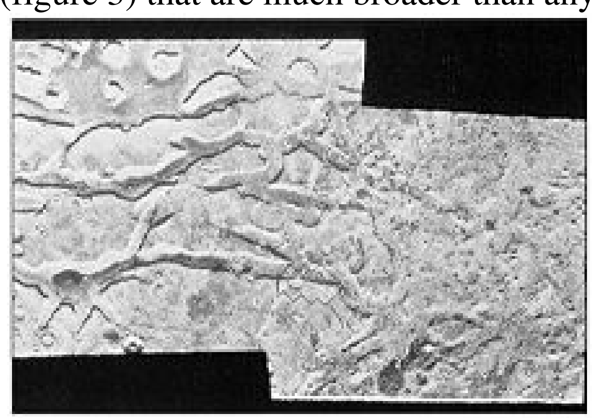

Figure 3

Figure 4

These and other features indicate that there was standing water on Mars three and-a-half billion years ago and episodic floods within the last several billion years. So, there was time for life to evolve before liquid water disappeared from the surface.

Recently, interest in the possibility of life on Mars was heightened by the examination of a meteorite from Mars (Figure 5). ALH84001, found in Antarctica in

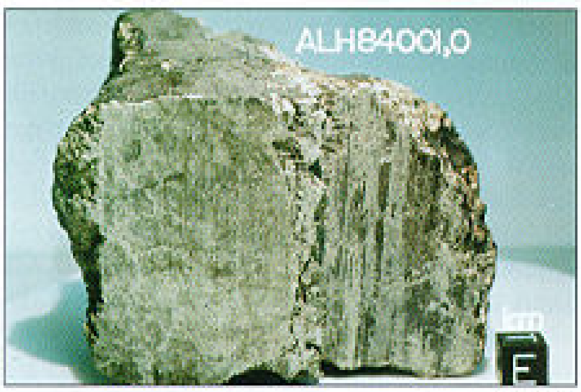

Figure 5

1984, was blasted off the surface of Mars by an impacting object 15 million years ago. We know that the meteorite came from Mars because the gases trapped in it are similar to those measured in the Martian atmosphere by Viking. ALH84001 came from that part of the Martian surface that is four billion years old, a time when water was abundant on Mars. There are 11 other known Martian meteorites that came from younger parts of the Martian surface that were covered by volcanic flows only one to one-and-a-half billion years ago when the surface was likely dry.

Knowledge of the age of ALH84001 led to the investigations that developed three lines of circumstantial evidence pointing to life. First, there are three-and-a-half billion year old carbonate deposits inside the crevices of the rock (Figure 6). Carbonates can be deposited by both non-living and living processes.

Figure 6

Second, microcrystals of magnetite, a magnetic mineral that can be deposited by bacteria, are associated with the carbonate. It has not been determined if the magnetite crystals found in ALH84001 were biologically produced, but they have a shape consistent with a biological origin. Third, there are polyaromatic hydrocarbons (PAHs) inside the rock where terrestrial contamination is unlikely. Some PAHs are the complex hydrocarbon residue from the decay of once-living matter. PAHs can also be produced chemically without life and are found, for example, dispersed through the interstellar medium. Although none of the evidence is proof that there was life on Mars, the investigators suggested that life was the simplest explanation for the presence of these three deposits together.

An electron micrograph (Figure 7) was taken of the deposits inside ALH84001 on a scale one-hundred times smaller than the photomicrographs in Figure 6. Although the structures in Figure 7 resemble microfossils, some investigators believe that they are not, because the features are much smaller than microfossils found on Earth and are too small to enclose large DNA molecules. Although the interpretations about the deposits in ALH84001 are scientifically controversial, many investigators are eager to apply their own specialized measurement techniques. Even if the evidence does not prove there was life, the suggestion is consistent with life having evolved three-and-a-half billion years ago when there was water on Mars.

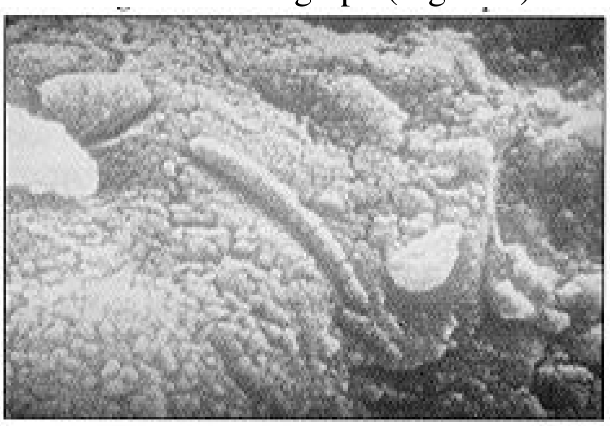

Figure 7

Thus, a first step in searching for evidence of life is to look for where there was water. This is the underlying strategy for exploring Mars. Every 26 months there is an opportunity to go to Mars, with the first two missions scheduled for launch in late 1996.

Exploring Mars

The first mission, Mars Global Surveyor, will be launched from Florida in November 1996 (Figure 8). It will arrive in September 1997, entering a polar orbit from which it will systematically examine the composition of the surface of Mars. Investigators will search for regions on Mars where there was thermal activity at one time, similar to Yellowstone National Park on Earth. Currently no active thermal spots are known, so the search will concentrate on the chemical signatures of past thermal regions. Using the spacecraft camera to image surface features only five feet across, it will be possible to examine areas where there was water, and therefore where life might have evolved.

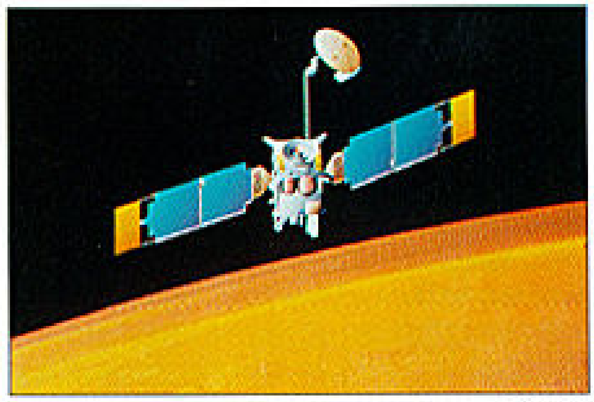

Figure 8

The second mission, Mars Pathfinder, will be launched in December 1996, traveling directly to Mars and landing on July 4, 1997. Surrounded by air bags, the lander will impact the surface, bouncing a hundred feet high until eventually coming to rest (Figure 9). Once it settles, the landing system, shaped like a tetrahedron, will open three outer panels covered with solar cells that will power the lander (Figure 10). One of the panels also carries the small rover, "Sojourner." The lander has a stereo camera that will be used to identify the most interesting rocks. The rover which is about a foot tall, weighs 25 pounds, and runs on an average power of eight watts will then be sent to investigate.

Figure 9

Although Sojourner is a small robot, it has the capability of avoiding rocks too large to go over and precipices too dangerous to negotiate. Steering the rover in real time from Earth is not possible because of the time delay in

Figure 10

sending instructions between Earth and Mars. So, we will specify a destination and allow the rover to find its own way to the rock. It will then place a small alpha-proton x-ray spectrometer against the rock to determine its chemical composition. As the rover roams about, it will determine the composition of a variety of rocks on Mars. Observing tiny features like those in ALH84001 would require a much more sophisticated technology; however, this is the first step of a systematic exploration of the surface of Mars.

The Pathfinder landing site was chosen at one of the outflow regions, a dry channel called Ares Vallis, where a great flood once flowed (Figure 11). The spacecraft will land far from the mouth of the channel to ensure that all the large boulders would have been left behind and the currents would have slowed down enough to have carried and deposited only smaller rocks. The target site, an ellipse of 60 by 120 miles, is called a grabbag site because the water will have carried in rocks from a wide region on Mars. This grab-bag will allow us to sample and analyze rocks from a wide region even though Sojourner will have a limited range.

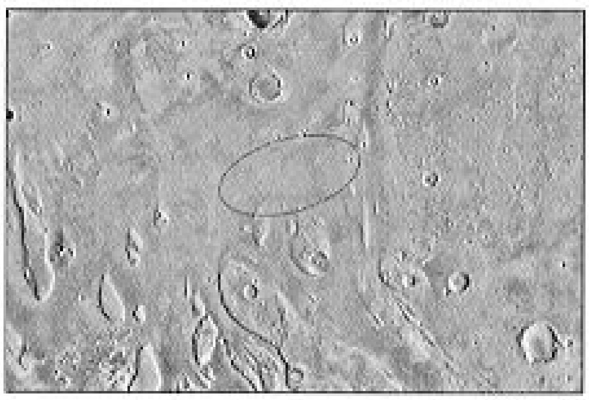

Figure 11

The landing site planned for the 1999 mission is near the South Pole of Mars where a polar cap of frozen carbon dioxide (dry ice) grows and shrinks with the seasons (Figure 12). At this landing site, which is within 10 degrees of the pole, the layered terrain is built up of wind blown deposits from many annual cycles.

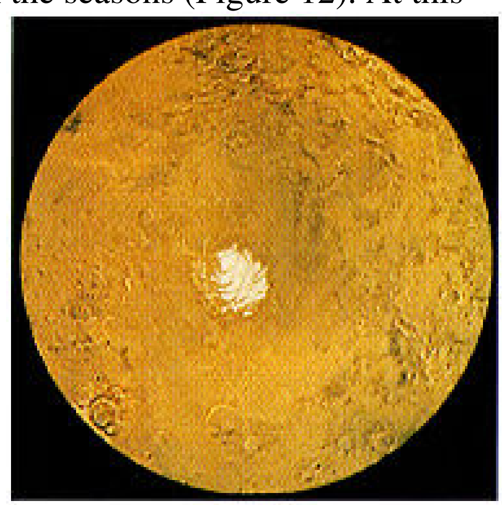

Figure 12

This Mars mission is the next step in searching for the most likely spots where water once existed on Mars and perhaps where it exists today as ice. A small stationary lander (Figure 13) will use a robotic arm to scoop up soil

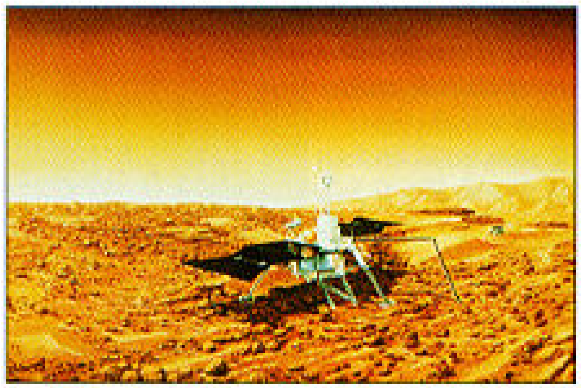

Figure 13

samples that will be heated so that volatiles such as water can be measured. We also hope to determine if there are organic compounds buried in the soil, protected from 'the hostile surface environment.

Our current plan (Figure 14) combines a series of orbiting and landing spacecraft. The orbiters will map the surface and analyze the atmosphere, allowing us to identify and evaluate the most interesting spots to land and explore.

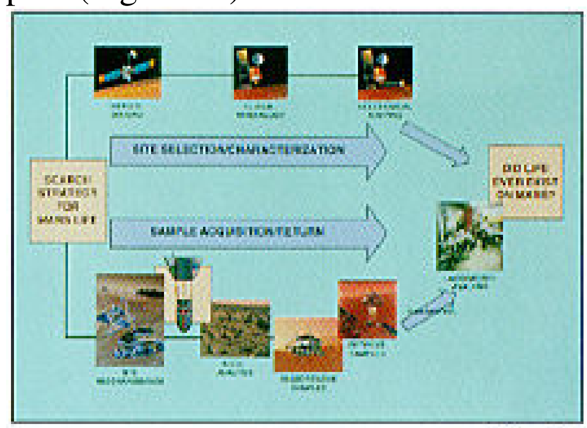

Figure 14

In 2001 and 2003 more advanced rovers will be sent to analyze rocks in greater detail and to select and cache those most likely to contain evidence of past or present life on Mars. A future mission could then land, pick up the samples, and return them to Earth. By taking advantage of launch opportunities every two years, it should be possible to return the first sample in 12 years.

Life on Europa.

While Mars is an exciting place to search for life else where, it is not the only place. On Earth, life began in the oceans and persists today without need for sunlight. Europa, a moon of Jupiter, may also have an ocean. About the size of Earth's Moon, its icy crust is the smoothest in the solar system (Figure 15), with no mountains or valleys and few impact craters.

Figure 15

Narrow white ridges, about 500 ft. high, are the highest features on Europa's frozen surface. These are accompanied by dark deposits (Figure 16) that suggest the ridges may have formed from eruptions from below the ice. Geologically, such eruptions are fairly recent because the paucity of impact craters indicates a young surface. We do not know if eruptions are still occurring. There are other features resembling an ice pack (Figure 17) that also suggest that there was liquid water at one time. A key question is whether a liquid water ocean is present today. As the Galileo spacecraft continues to orbit Jupiter, it will fly by one of the four large moons about every two months. In December 1996, Galileo comes within 400 miles of Europa, close enough to resolve surface features only 20 feet across. Europa is revisited again in February and November 1997, and will be the focus of a two-year extended mission beginning in 1998.

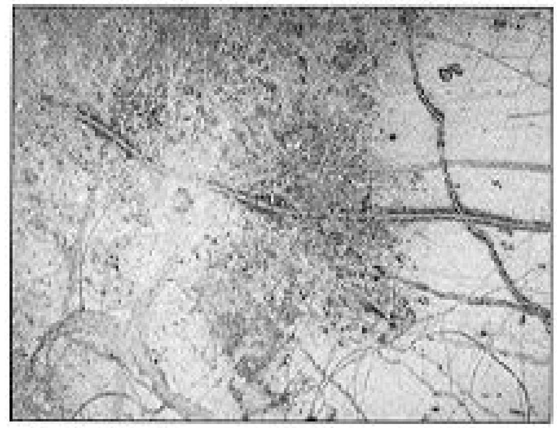

Figure 16

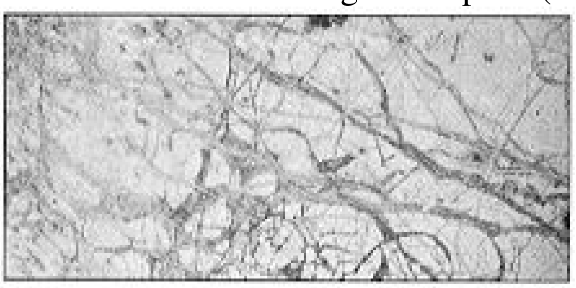

Figure 17

The high resolution images from these flybys may provide evidence for the possibility of a liquid water ocean under Europa's icy crust. In that event, future missions would return to Europa, first to determine the thickness of the ice, and then to search on and beneath the surface for any evidence of life.

Titan

The solar system holds other places of biological interest. Saturn's moon, Titan (Figure 18) is especially interesting. Titan is as large as the planet Mercury and, unlike any other moon, has' a substantial atmosphere with a surface pressure 60 percent greater than on Earth. Titan's atmosphere, like Earth's, is 80 percent nitrogen, but unlike Earth, it has significant methane and no oxygen. On Titan, sunlight creates a smog of complex hydrocarbons, forming a fuzzy opaque haze that blocks a view of the surface. The organic chemistry occurring here today may, in some ways, resemble that which occurred in the Earth's early atmosphere.

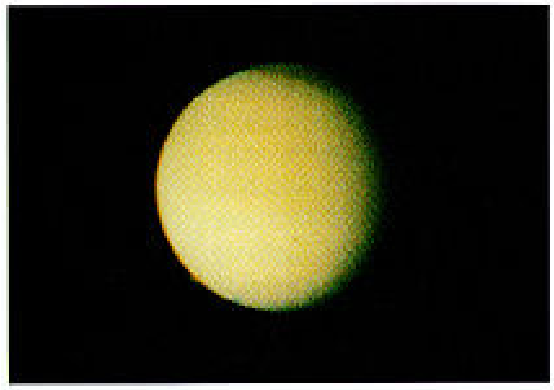

Figure 18

Cassini, a joint mission between NASA and the European Space Agency (ESA), is planned for launch in October 1997, arriving at Saturn in 2004 (Figure 19). As the spacecraft orbits Saturn, it will fly by Titan, imaging the surface beneath the opaque haze with a radar system developed jointly with the Italian Space Agency. The spacecraft also carries the Huygens atmospheric probe developed by ESA that will carry a set of instruments into Titan's atmosphere to analyze the organic chemistry occurring there.

Figure 19

Titan may hold important clues to the origin of life in the solar system. Just as the Earth's polar caps retain layer by layer of frozen evidence of past climate, the surface of Titan may have layer by layer of frozen organic compounds from past eons of atmospheric chemistry. Eventually technology will allow us to learn what that history has to teach us.

Comets

Comets hold another place of interest in the study of life in the solar system. They are not likely to harbor life, but they may have had an important role in its evolution. There was a lot of water ice when the solar system formed, and the ice and rock formed large comet-like objects, some of which collided and coalesced to form the cores of the giant planets. Others were scattered to the outer solar system from where a few occasionally return as comets.

Although comets are mainly water ice, their surfaces are charcoal black. When the European spacecraft Giotto flew by Comet Halley in 1986 (Figure 20), it analyzed the material coming off the surface. Although its instruments could not identify molecular compounds, Giotto did find that the atomic constituents of the escaping material were hydrogen, nitrogen, oxygen, and carbon the building blocks of organic molecules. Where did this black material come from? Was it the interstellar matter out of which the solar system formed? What role did this black material have in seeding the inventory of organic compounds that were in the Earth's ancient oceans and, perhaps, on other planets before life evolved? We cannot answer these questions unless we know what the black material is.

Figure 20

One way to obtain a sample of this substance is to fly through a comet's coma and capture the dust. Because the flight through the coma is so rapid, any material captured on a solid surface would evaporate on impact. To collect the comet dust, a material called aerogel (Figure 21) will be used. This silica material is so porous that its density is no more than that of air. Even at a flyby speed of 12,000 mph, the tiny dust particles will be captured intact in the aerogel for return to Earth.


Figure 21

The Stardust spacecraft will be launched in 1999 for an encounter with Comet Wild II in January 2004. A sample will be returned to Earth in January 2006, for analysis of its organic constituents. This material should provide important clues about the contribution comets may have made to the inventory of organic compounds in the oceans before life evolved.

Stellar Nurseries and Protoplanetary Discs

The search for life also extends beyond the solar system. An image taken recently by the Hubble Space Telescope (Figure 22) shows clouds of dust and gas 7000 light-years away. These are the stellar nurseries of the Eagle Nebula places where stars and their planetary systems are born. The clouds, up to a light year in extent, are surrounded by bright stars that irradiate and evaporate them. New stars are born by the collapse of dust and gas within the cloud and are revealed as the surface of the cloud around them evaporates.

Figure 22

The stellar nursery in the Orion Nebula (Figure 23) is five times closer than the Eagle Nebula. The fuzzy nebulosity in this Hubble image is less than one million years old, as are the newborn stars. More than twenty percent of the approximately 700 young stars in this image are surrounded by discs of dust from which planets are thought to form. Figure 24 shows the discs of dust surrounding four of these stars. These discs range in size from about that of the solar system to several times larger. They have about the right mass to conglomerate into planets, but have not yet done so.

Figure 23

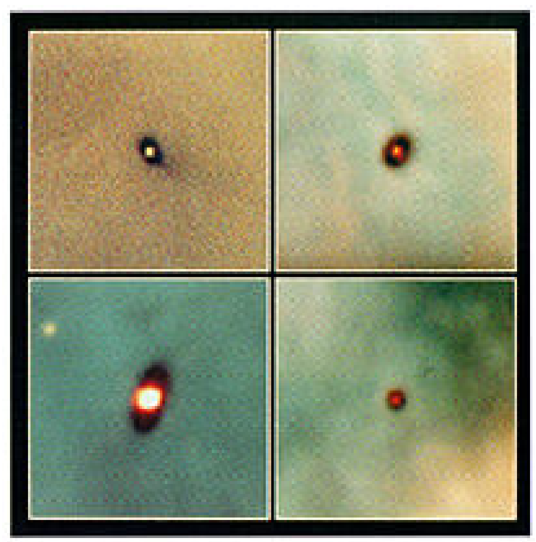

Figure 24

Recent calculations suggest that, of stars with a mass between half to one-and-a-half times that of the Sun, five to ten percent will have a planet in a habitable zone not too close to its star to be baked or too far to be frozen. When you consider how many stars there are just in the Milky Way galaxy-hundreds of billions as well as other galaxies, there are likely to be many other planetary systems. In late 2001, the Space Infrared Telescope Facility (Figure 25) will be launched to search for such discs and nascent planetary

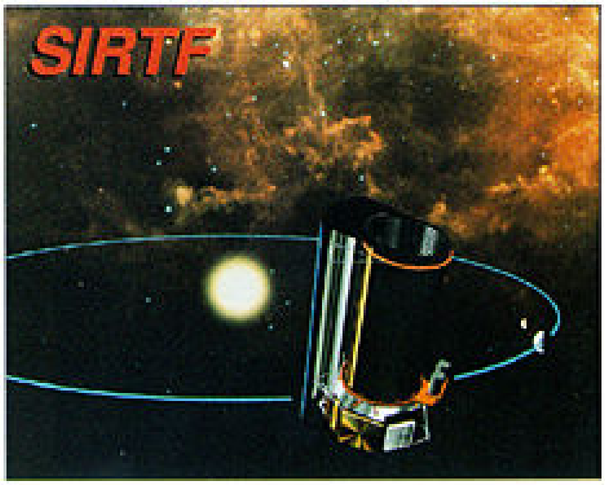

Figure 25

systems. Searching for Extrasolar Planets. There is direct evidence for a Jupiter-like object in orbit about the red dwarf star Gliese 229B (Figure 26). The object has a mass more than 20 times that of Jupiter and an atmosphere cool enough to have methane.

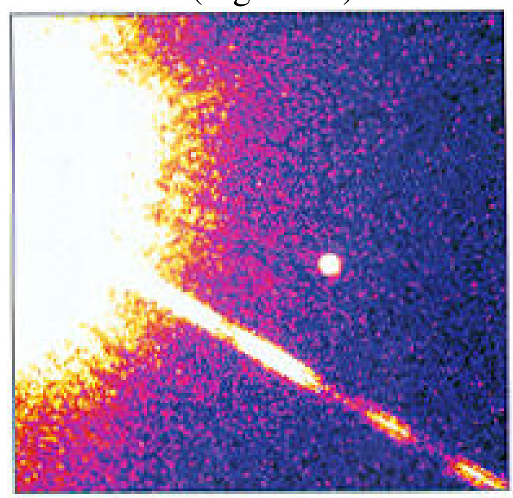

Figure 26

Recently a number of extrasolar planetary systems (Figure 27) have been inferred from the wobble of the star induced by the orbital motion of the planets. The star 47 Ursae Majoris has a planet about 2.4 times more massive than Jupiter at a distance twice that of the Earth from the Sun. Two of the planetary systems have large planets close to their stars, contrary to expectations. We expected that rocky objects like Earth would form close to their stars. Yet the star 51 Pegasi has a Jupiter-like planet orbiting so close that it completes its "year" in only four days. The fact that such large planets have been found so near stars is not because they are necessarily typical, but because they are more easily detected with current technology.

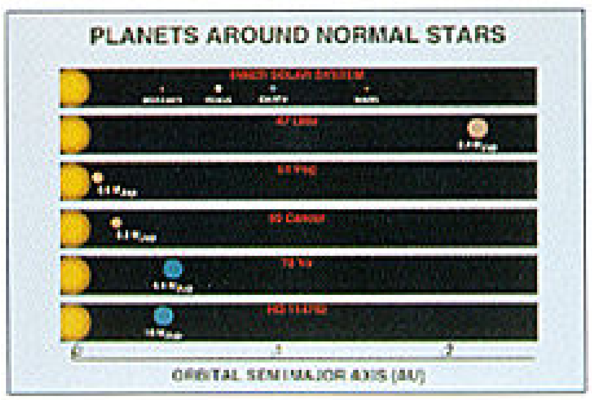

Figure 27

There is now no question that there are other planetary systems, but that is not a surprise. Many scientists believed that there were other solar systems and we now have evidence of their existence. The challenge now is to undertake a systematic exploration of planets around other stars.

One of the first steps is underway with the twin Keck telescopes (Figure 28). These 10-meter

(33-foot) telescopes are the two largest optical telescopes in the world. Their incoming light can be combined so that the two mirrors will act as if they were part of a mirror as large as the 85-meter distance between the two telescopes. This would provide the visual acuity of an 85-meter telescope. Such *interferometry* techniques will allow us to find Jupiter like planets orbiting nearby stars.

Figure 28

If there are giant Jupiter-like planets orbiting nearby stars, models of planetary formation suggest that closer to the star there will be Earth-like planets. However, the ground-based Keck telescopes will not be able to find such Earth-like planets because they would be lost in the glare of the light from the star that is one billion times brighter. Using the same technology in space, however, multiple telescopes could be separated far enough (Figure 29) so that individual Earth-like planets could be imaged. Individual planets will be points of light that can be analyzed to determine the chemistry of each planet's atmosphere. The presence of oxygen, water, and methane would be evidence that simple life may have evolved.

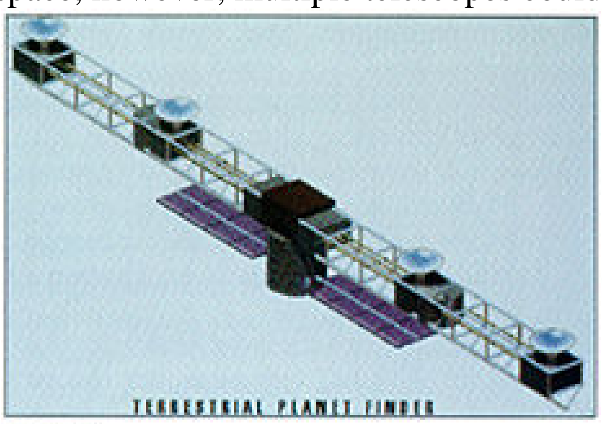

Figure 29

It will take about a decade to develop the technology for a planetfinder telescope. There is a prototype interferometer at the Palomar Observatory in California, and over the next several years a full-scale system will be installed at the Keck Observatory. Experience with these ground-based systems will enable us to design and develop the ultimate space-based observatory that will extend our search for life beyond the solar system.

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